Multi-Layered MoS\textsubscript{2} Thin Film Formed by High-Temperature Sputtering for Enhancement-Mode nMOSFETs

T. Ohashi\textsuperscript{1}, K. Suda\textsuperscript{2}, S. Ishihara\textsuperscript{2}, N. Sawamoto\textsuperscript{2}, S. Yamaguchi\textsuperscript{1}, K. Matsuura\textsuperscript{1}, K. Kakushima\textsuperscript{1}, N. Sugii\textsuperscript{1}, A. Nishiyama\textsuperscript{1}, Y. Kataoka\textsuperscript{1}, K. Natori\textsuperscript{1}, K. Tsutsui\textsuperscript{1}, H. Iwai\textsuperscript{1}, A. Ogura\textsuperscript{2} and H. Wakabayashi\textsuperscript{1}

\textsuperscript{1}Tokyo Institute of Technology
4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa 226-8502, Japan
Phone: +81-45-924-5847, E-mail: ohashi.t.af@m.titech.ac.jp
\textsuperscript{2}Meiji University, 1-1-1 Higashi-Mita, Tama-ku, Kawasaki, Kanagawa, 214-8571, Japan

Abstract

Multi-layered MoS\textsubscript{2} film of sub-10-nm formed by high-temperature sputtering has been investigated for enhancement-mode nMOSFETs. Raman peak of MoS\textsubscript{2} was observed even by using high-temperature sputtering. In addition, Hall mobility of sputtered MoS\textsubscript{2} film is obtained and it is considered that the enhancement-mode nMOSFETs could be realized through the decrease in carrier density and surface charge density.

1. Introduction

Molybdenum disulphide (MoS\textsubscript{2}), one of the transition-metal dichalcogenides and has been used for solid lubricant so far, has attracted grate attention thanks to its wonderful characteristics such as flexibility, transparency and having energy band gap ($E_g = 1.8$ eV) [1]. In addition, MoS\textsubscript{2} has comparably high mobility (~700 cm$^2$/V s) even in thin region as shown in Fig. 1.

All of devices using MoS\textsubscript{2} so far have been depletion-mode and n-type. The reason of the depletion-mode operations are considered as unintentional n-type doping to the channel during the process of the production [1, 2]. K. Dolui, et al., suggested that when Na atom is placed on the interface between SiO\textsubscript{2} and MoS\textsubscript{2}, the electronic structure of the composite is strongly affected by the presence of Na ion and the system becomes n-type [3]. Therefore, in order to avoid Na contamination, the clean processes are needed to realize the enhancement-mode MoS\textsubscript{2} MOSFETs. In such phenomena, sputtering could be a candidate to realize enhancement-mode MoS\textsubscript{2} MOSFETs. Regarding sputtered MoS\textsubscript{2} has already reported in a thicker region (>10 nm). In addition, carrier density (n-type) decreased compared to reported devices (ref. 7). Fig. 8 shows the simulated and reported threshold voltage. The simulation used the structure and the surface charge density ($n_s$) of ref. 2, and the carrier density of ref. 7. The results indicate that the mitigation of the carrier density and the surface charge density makes the threshold voltage plus, i.e., the device could be the enhancement-mode.

3. Conclusions

Thin film of MoS\textsubscript{2} was obtained by high-temperature sputtering and its carrier density is comparatively low compared to reported results. That fact shows the possibilities of realizing the enhancement-mode MoS\textsubscript{2} nMOSFETs with sputtering method. In order to achieve high mobility MoS\textsubscript{2} film, the improvement of the sputtered film quality will be the essential work in the future.

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References

Reported MoS$_2$ MOSFETs [1, 2];

Exfoliation CVD

Sputtering can be a method of fabricating large-scale high mobility MoS$_2$ film with relatively low temperature.

Fig. 1 Advantages of MoS$_2$ and sputtering method to fabricate MoS$_2$ film. When silicon, which is widely used for advanced LSIs, becomes thin film, the mobility deterioration will occur. In such region, MoS$_2$ has relatively high mobility. Sputtering method has good properties such as large-scale formation, low temperature (conventionally 650°C~ by CVD [1]) and commonly used process in LSIs production.

Fig. 2 TEM image of sputtered thin MoS$_2$ film. Five layers of MoS$_2$ film are seen. It is formed on SiO$_2$ substrate, therefore, it can be applied to the transistors of LSIs.

Fig. 3 TEM image of sputtered MoS$_2$. Two regions can be seen, one is horizontal layers and another is perpendicular layers to the interface.

Fig. 4 RMS roughness of sputtered MoS$_2$ using AFM. Growth directions can be identified by changing the slope at 10 nm.

Fig. 5 Raman spectra of high- and room-temperature sputtered MoS$_2$ film (10-nm thick).

Fig. 6 Raman spectra of high-temp. sputtered MoS$_2$ on its thickness. As the thickness thinner, the difference between the peak of E$_{2g}$ and A$_{1g}$ narrows in usual. However, sputtered MoS$_2$ film performs opposite behavior with reported devices so far.

Fig. 7 Hall measurement results of high-temp. sputtered MoS$_2$. Carrier density (n-type) decreases compared to exfoliated film [7]. Thin film has relatively high mobility and low carrier density thanks to no perpendicular layers.

Fig. 8 Simulated threshold voltage dependence of n-type accumulation MOSFETs on carrier density and surface charge density ($n_s$) of MoS$_2$. This simulation used the structure, carrier density and surface charge density in refs. 2 and 7.